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Review of Geography
Internship on Convective Wave Project

by

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I. Introduction

The purpose of this paper is to examine in detail my internship for the University of Northern Colorado, fall semester of 1989. I will describe the acquisition of the internship, the personnel of the project, the project itself and the goals associated with it. I will also describe my orientation to the internship, the project's operations, and the conclusion of the findings.

I initially contacted the University of Colorado's Geography Department during May of 1989 to discover any possible internships available to students from other universities. At the time I was attending California State University at Northridge, through the National Student Exchange program of which U.N.C. is a member. Knowing that I wanted to reside in Boulder, I was interested in an internship in the area. I was informed by the C.U. Geography Department that I would only be able to choose from those internships that were not filled by C.U. students. I made note of one internship entitled "Convective Waves Project," from a Dr. Robert Grossman of CIRES (Cooperative Institute for Research in Environmental Sciences), University of Colorado, Boulder. He was looking for one or two interns for the summer and fall semesters. When I returned to Colorado in August of 1989, I met with Dr. Charles Collins of the U.N.C. Geography Department. I was seeking his approval of an internship through the C.U. Geography Department. After receiving Dr. Collins' approval, I interviewed for the internship with Dr. Grossman and had my transcripts from U.N.C. and C.S.U.N. sent to CIRES. I also referred him to the C.U. Geography Department to read letters of recommendation from a few of my former geography professors.

Since this process took some time it was about a week into U.N.C.'s fall semester when I was accepted into the internship.

The internship took place at CIRES, which is a branch of the University of Colorado's Boulder campus. I worked under the direction of Dr. Robert Grossman who is with CIRES, and Dr. Joachim Kuettner who is with NCAR (National Center for Atmospheric Research). I worked most closely with Dr. Grossman, who is located in Research Laboratory-2; this was the same building I worked in. I also worked with Kurt Van Speybroeck, an intern from the University of Colorado's Geography Department. He had worked with Drs. Grossman and Kuettner for the summer semester and was continuing his internship into the fall semester.

When I was read the description of the internship over the phone I did not fully comprehend what a convective wave was. I was familiar with mountain waves and the lenticular clouds associated with them, but I needed more information on what Drs. Kuettner and Grossman were researching. The difference between convective waves and mountain waves was found to be that the former occur over flat terrain. Convective waves are internal gravity waves that are within the troposphere (and possibly stratosphere) generated by a convectively active boundary layer (Grossman, 1989). Convective waves were first discovered and utilized by glider pilots. These waves enable sailplanes to climb upstream of cumulus clouds well above cloud tops (see Figure 1).

> Convection waves are a strong function of the original forcing by convection in the boundary layer. This convection can take the form of random or two-dimensional spatial structure. When clouds are formed as a result of two-dimensional boundary layer forcing (horizontal roll vortices) they are called cloud streets. Cloud streets when formed under conditions of cold or warm advection (which account for necessary

> shear) provide a very strong forcing for convection waves since the streets act like a periodic obstruction to the flow, enhancing the formation of waves. (Grossman, 1989)

For our purposes, research of cloud streets focused on the coasts off East Asia and Eastern North America, during the winter season. That is the time when very cold dry air, originating from the Arctic, descends over the continents and flows over the Kuroshio (Japan Current) or the Gulf Stream. These warm water currents and their relative locations off the continents make the atmosphere over them favorable for formation of convective waves, and cloud streets (see Figure 2).

II. Project Goals

After this somewhat detailed description of convective waves and the important cloud street formation associated with them, I will now address the convective wave research project goals, and how my internship helped to achieve some specific goals. The overall goal of the project was to determine the effect of convective waves on wind speeds in the middle and upper troposphere, and how these waves affect the general circulation on a global scale. "Internal waves have the potential of extracting westerly momentum from the atmosphere. Present forecast modes consistently overestimate westerly winds and this is one of the limits to accurate numerical weather and climate forecasts" (Grossman, 1989). This is important to note because the wind speeds of the jet stream are probably affected by convective waves. A more specific goal of the project which my internship focused on was the satellite analysis of cloud street formations. This was done to determine frequency and areas in which cloud streets occur off the East Asian and North American coastlines. I also noted other areas in the

Northern Hemisphere where cloud streets occur. This research will assist global numerical forecast models, aircraft investigation off the east coast of North America, and provide cartographic results showing frequency and areas of cloud streets during a given time period.

III. Project Orientation

When I began my internship I needed to be oriented to the various aspects of the internship. First I was introduced to the project, and the work I would be doing. Second, I was oriented to the CIRES organization and building, RL-2 where I would be working. Third, I was oriented to the data I would be using and the materials used.

Dr. Grossman spent some time with me each day during the beginning of my internship orienting me to the project and work I would be involved with. Kurt Van Speybroeck was not present when I began due to his absence from the country. This proved to be somewhat of an inconvenience for Dr. Grossman and myself, but Dr. Grossman resolved this by having me work on jobs that had already been completed by K. Van Speybroeck. He also gave me materials on convective waves to read. I also used Dr. H. Reihl's "Introduction to the Atmosphere" for basic meteorological concepts I needed to understand. Dr. Grossman checked my work and compared my results with K. Van Speybroeck's. He continued to check my work at regular intervals throughout the duration of the internship.

I was also oriented to the CIRES organizational structure by Dr. Grossman. He showed me where I would be working; also where I would find some materials and support I might need, including the front office. My orientation to data and materials was also critical and handled by Dr.

Grossman. The National Snow and Ice Data Center (NSIDC), located here at RL-2 has established a collection of satellite imagery acquired from the United States Air Force Defense Meteorological Satellite Program (DMSP). DMSP is a system of near-polar orbiting satellites providing information in two spectral bands, visible and infrared. This was the data source used during the internship. Dr. Grossman also introduced me to the materials I would be using to accompany the satellite data. When Kurt Van Speybroeck returned, he oriented me to the Numonics 2300 digitizer and the 855 computer commands I would be using. He also went over some fine details I would need to make my work efficient and productive.

IV. Project Operations

After being oriented to the project, CIRES and the data and materials I would use, I was instructed on how the actual work was done, from research analysis to the final cartographic display. I will now detail each step and give any pertinent information that was useful in the internship and project. Those steps were analysis of individual days, photocopying, digitizing and retrieving data, running the "atotal" program, permanent storage of data, and finally contouring and modifying the "atotal" results that produced the final cartographic product.

The first step of the process was analysis of individual days using the DMSP 1:30,000,000 polar stereographic projections. These mosaics are compiled from several orbital strips and have a resolution of 5.4 km. Visual mosaics were primarily used for analysis. However, since cloud streets are a low-level phenomenon, infrared images were used to discriminate between cloud streets and high level gravity-wave clouds, which have the same visual appearance as cloud streets. Infrared mosaics were used when visible mosaics were missing. Each day had two separate analyses; one for the North American continent's coastline and one for the Asian coast's. The satellite image was backlit on a light table and a mylar overlay with the coastline and latitude, longitude locations critical to alignment were matched to each other. The areas of cloud streets were noted as well as the date and time of their occurrence. When working on already-completed analysis for December 1985, I noticed mistakes in the time zone figurations. This made the analysis one day off in this month for the Asian analysis. It was critical to figure how many hours to add or subtract from Greenwich time according to the time zone the cloud streets were located in, and when the satellite image was taken.

When researching and noting cloud streets on the mylar overlays it was important to photocopy each day for a permanent record. After one month had been analyzed and each mylar had been photocopied, the china marker that is used for analysis was cleaned off the mylar for reuse. Digitizing was the next step in the process. Each mylar overlay has a three-point set-up for use with the digitizer, and I should note that all the preliminary work had already been done by K. Van Speybroeck during his summer internship. This allowed me to concentrate on analysis and digitizing during my internship since much of the preliminary research work had been completed. The digitization process takes the cloud street information analyzed in polar stereographic form and converts it to a usable mercator projection form. This information was stored in data files on the NOAA 855 computer. To begin digitizing I logged on to the terminal hooked up to the Numonic 2300 digitizer and created a file for each day of the month for both the North American and Asian continents. For the exact process of digitizing see attachment 1. The continent's printouts for each day were sent to the laser printer located in the World Data Center's computer in RL-2. About five files at a time were sent to the printer in order to avoid tying up the printer for long periods.

After the entire month had been digitized an "atotal" program was run. This program sums all the days of the month and plots the areas in which cloud streets have occurred. The "atotal" program was run for each continent. The crude cartographic result was printed out and then enlarged on a photocopier to 130%. This was saved for later analysis and modification.

The digitized data files were permanently stored on floppy disks by entering the 855 computer and accessing the Kermit editor. The Kermit editor rejects bad data and will notify the user of any system failure. Files were stored on disk and purged from the 855 computer when the "atotal" program had been run and completed.

The final step in the process was modifying the "atotal" result in production of the final cartographic product. As I have noted, the 130% photocopied enlargement was used to draw contour intervals around and between the areas in which cloud streets occur. This is a dasymetric surface with a contour interval of four days. K. Van Speybroeck had produced some overlays of the latitude, longitude lines that also included the coastlines. These were to be used to match up to the 130% "atotal" enlargement. After all the proper enlargements were lined up, and the latitutde, longitude lines were drawn, the final map was reduced to fit on an 8 1/2" x 11" format. While inspecting some completed final maps, I noticed errors in the longitude lines, so I did not use the overlays produced for my own final maps. I have this as a project for the future. I also noticed that a previous method of depicting the dasymetric surface was incorrect. The maps used varying textures instead of tones to show the stepped statistical surface. I did manage to produce an incomplete, but so far correct, cartographic product for the internship and have included it within this paper. I also have included one of the earlier versions of the final maps.

V. Conclusion

In conclusion I will focus on how the internship influenced the convective wave project by verifying major Northern Hemisphere cloud street areas, and noting their frequency of occurrence and area. I will also note the influence of convective waves and how they are used to speculate on recent climate variability.

It can be noted with accuracy that the two areas under study, North America's and Asia's coastlines, are ideal for convective wave research from November through February. I would estimate that within our research area cloud streets were documented 80%-90% of the time.

Other areas in the Northern Hemisphere are also worth recognizing for cloud streets. These are the Barents, Bering, Norwegian and North Seas, and also the East Atlantic Ocean in the mid to high latitudes. Occasionally cloud streets occur in the stratus off Southern California and the Baja California Peninsula. Cloud streets sometimes occur over unusual areas or only once in a while over some areas. I have noted their occurrence over the Black and Caspian Seas, as well as the Red Sea and Bay of Bengal. This would indicate a very cold and strong air outbreak from the continent reaching over long distances and/or strong air-sea temperature differences. Occasionally during large outbreaks over the East coast of North America the cold air reaches out over the Gulf of Mexico and streets form. This phenomenon, associated with low temperatures in the Gulf Coast States, is of special interest to Dr. Kuettner. I may be focusing on diurnal variation of cloud streets in the Gulf in the future.

Climatological maps of sea surface temperature (SST) and sea level pressure were supplied by Dr. Joe Fletcher, who directs the NOAA Environmental Research Laboratories. These maps assist us in speculating on recent climate variability. Figure 3 shows two areas in the Northern Hemisphere which had significantly cooler SSTs in the period 1971-1987 compared to 1954-1971. These areas of cooler SSTs are nearly co-located with areas of maximum occurrence of cloud streets. Since cloud streets are associated with cold air outbreaks and large fluxes of thermal energy from ocean to atmosphere (Grossman and Betts, 1990), these areas of lower sea surface temperatures may reflect either more intense and/or more frequent cold air outbreaks during the 1971-1987 period compared to the 1954-1971 period. Cold air outbreaks over warm water currents cool the sea surface temperature by evaporation, the transfer of sensible heat, and by mixing of the warmer surface water with the cooler water below. Fletcher's sea level pressure map (Figure 4) is consistent with the hypothesis that cold air outbreaks were more intense in the 1954-1971 period rather than more frequent. Higher pressures would be associated with stronger cold air outbreaks rather than more frequent ones, whose pressures may not have changed much from one period to the next. Therefore, the co-location of maximum SST cooling and higher pressures is consistent with an hypothesis of more intense cold air outbreaks. Lower SSTs are co-located with higher sea level pressures off the Asian coast near Japan. The situation is different, however, off the North American coast. There are two distinct areas of high and low pressure bisected by the Ø line located in the mid-Atlantic Ocean. The area of high pressure shows the area of cold air outbreaks and cloud streets while the area of low pressure indicates the area where the storm tracks lie. Deepening cyclones, as they move out to sea, also extract large amounts of thermal energy from the ocean. The North American SST cooling may be the result of air-sea interaction associated with cold air outbreaks and the preceding cyclonic storm. Our combined research will continue to look into this intriguing set of observations.

VI. Works Cited

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